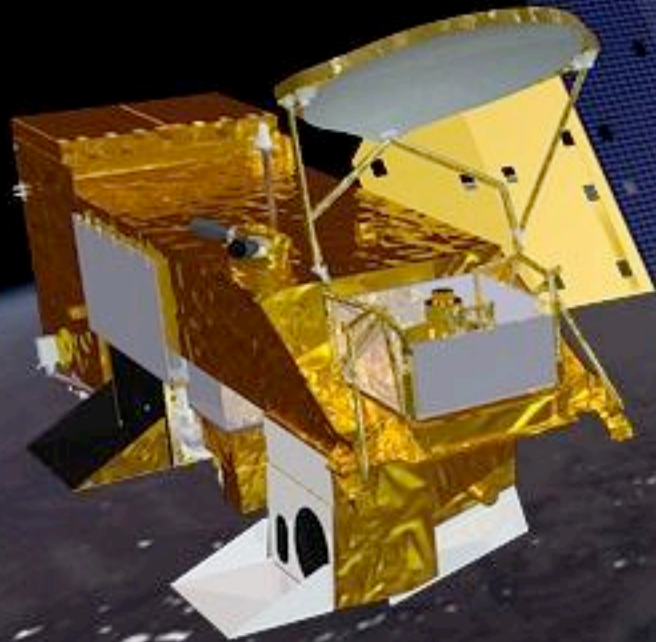


EOS Aqua

AMSR-E Recovery



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Earth Observing Missions



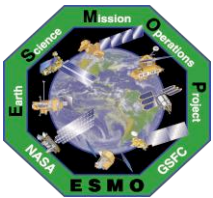
**AMSR-E Stage 2 Recovery Meeting
NASA Goddard Space Flight Center
July 18-20, 2012**



Introduction/Background



- **Aqua AMSR-E instrument spun down in October 2011**
- **JAXA proposed a 3-Stage Recovery Plan for AMSR-E in January 2012**
 - Stage 1: Observations without antenna rotation
 - Stage 2: Run-up to around 4 rpm within one real-time contact
 - Stage 3: Continuous observations around 4 rpm
- **Purpose of run up to 4 rpm is to allow cross-calibration with AMSR2**
- **GCOM-W1/AMSR2 successfully launched in May 2012**
- **Aqua spacecraft was healthy and all subsystems were on prime hardware**
 - All functioning Aqua instruments were healthy and operating fine
- **Joint NASA/JAXA Team developed a low-risk Recovery Plan**
 - Initial attempts to spin to 4 rpm were unsuccessful (JAXA requested ~2 rpm)
 - Instrument was successfully spun up to 2.076 rpm in December 2012

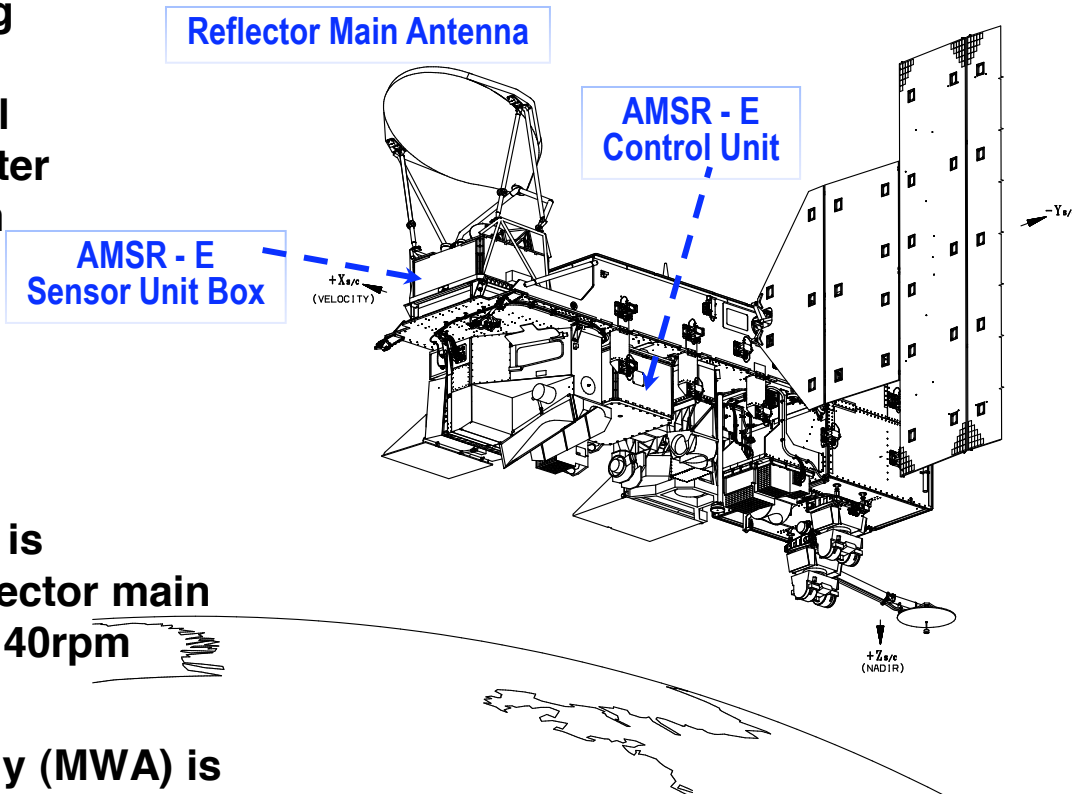


AMSR-E Instrument



The Advanced Microwave Scanning Radiometer for EOS (AMSR-E) is a twelve-channel, six-frequency, total power passive-microwave radiometer system that measures precipitation rate, cloud water, water vapor, sea surface winds, sea surface temperature, ice, snow, and soil moisture.

- Antenna Drive Assembly (ADA) is responsible for rotating the reflector main antenna and sensor unit box at 40rpm
- The Momentum Wheel Assembly (MWA) is located within AMSR-E control unit. It is responsible for counteracting any angular momentum generated by the ADA





AMSR-E Challenges (Pre-launch)



- Recognized before launch by the Aqua Project and spacecraft manufacturer that the AMSR-E instrument posed some special challenges to the spacecraft and mission
- The AMSR-E sensor is a large (1.6m, 220 kg) parabolic antenna that rotates at 40 RPM about the spacecraft –Z axis and generates about 240 Newton-meter-second (NMS) of momentum which is counterbalanced by an internal instrument Momentum Wheel Assembly (MWA) rotating at 3700 RPM
- Uncontrolled momentum shutdown in AMSR-E will result in severe spacecraft upset (antenna spins down much more rapidly than MWA)
- Spacecraft Guidance Navigation & Control (GN&C) wheel-based control system cannot recover nor hold sun orientation until AMSR-E momentum wheel stops
- Baseline spacecraft design (CDR) approach precluded the automatic use of thrusters for fail-safe operation
- Aqua Project Office/NASA issued technical direction to allow autonomous entry into a thruster controlled mode for this special case

The Stage 2 Spin-Up/Spin-down test limits rotational speed to approximately 4 RPM, therefore limiting the maximum possible momentum dump into the spacecraft to approximately 36 NMS which is well within *the approximate 120 NMS capabilities of the spacecraft reaction wheels.*

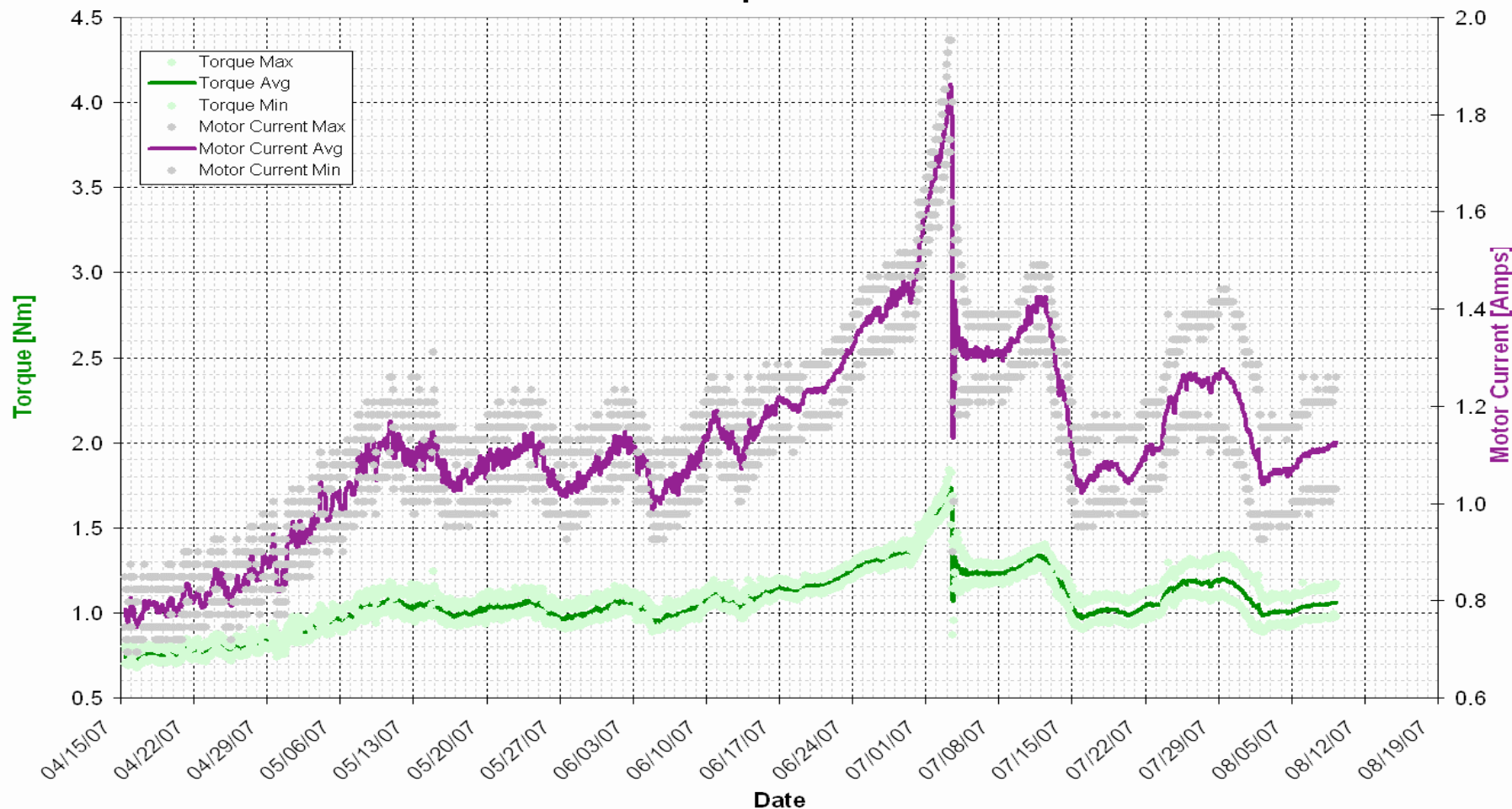


ADE Motor Current & Torque

(April – August 2007)



Commanded Torque & Motor Current





AMSR-E Challenges

(Post-launch)



- Recognized by the ESMO Project that the AMSR-E instrument posed some special challenges to the spacecraft and mission – Potential to tumble the spacecraft
 - Potential for autonomous back-orbit change to operational orbit
- 5 years into the Aqua mission the AMSR-E instrument began exhibiting signs of wear and tear
 - Similar to QuikSCAT experience
- The Flight Support Team undertook a multi-year development effort (4+ years) to implement onboard telemetry monitor (TMON) based logic to prevent the spacecraft from unnecessarily entering safe or survival state due to a AMSR-E Antenna anomaly
 - Full complement of protective logic was enabled in April 2011
- AMSR-E Antenna Drive Assembly (ADA) Anomaly and spin down to 0 RPM on October 4, 2011
 - Even with TMON-based protective logic spacecraft nearly entered safe state

The majority of the momentum dump into the spacecraft during the October 4, 2011 spin-down occurred during the spin-down from 40 RPM to 4 RPM. During the spin-down to 4 RPM, AMSR-E dumped ~33 NMS into the spacecraft for roughly 2 minutes. Spacecraft reaction wheels restored spacecraft pointing within 14 minutes.

The AMSR-E instrument did not have sufficient command authority to maintain 4 RPM and only achieved ~2.5 RPM. Once 2.5 RPMs was achieved, the AMSR-E MWA minimized the momentum dump into the spacecraft by counterbalancing AMSR-E's unsteady performance and spin-down to 0 RPM.



AMSR-E Anomaly

(Summary 2007 – 2009)



- **April 2007: Noticeable increase in Antenna Drive Assembly (ADA) motor current and commanded torque was observed**
- **June 2007: Changed Motor Torque Limit from 3.5 Nm to 4.5 Nm**
- **August 2007: Meeting with AMSR-E Team in Montana**
 - Reviewed Contingency Procedures (Red Limits) for a failure and spin-down to 4 RPM
- **July 2008: Meeting with AMSR-E Team in Colorado**
 - Further discussions of Red Limit response and spin-down to 4 RPM
- **March 2009: Honeywell Satellite Systems provided Mitsubishi/JAXA their analysis that projects life expectancy and suggests how to maximize remaining life**
 - Recommends disabling instrument fault management that would electrically disconnect the ADA/MWA in the event of an over-current/over-torque event
- **March 2009: ESMO/AETD Engineering Team (Schepis & Dube) Meeting**
 - Re-affirmed that 01/07/09 event was continuing signs of lubricant deterioration
- **June 2009: ESMO/AETD Engineering Team (Schepis & Dube) met to review Honeywell findings and recommendations – in basic agreement with findings**
- **October 2009: Meeting with AMSR-E Team and AETD Engineers at GSFC**
 - NASA/JAXA discuss Telemetry Monitors (TMONs) to monitor ADA performance at 40 RPM
- **December 2009; JAXA sends NASA request to develop 40 RPM TMONs**
 - NASA develops three (3) 40 RPM TMONs:



AMSR-E Anomaly

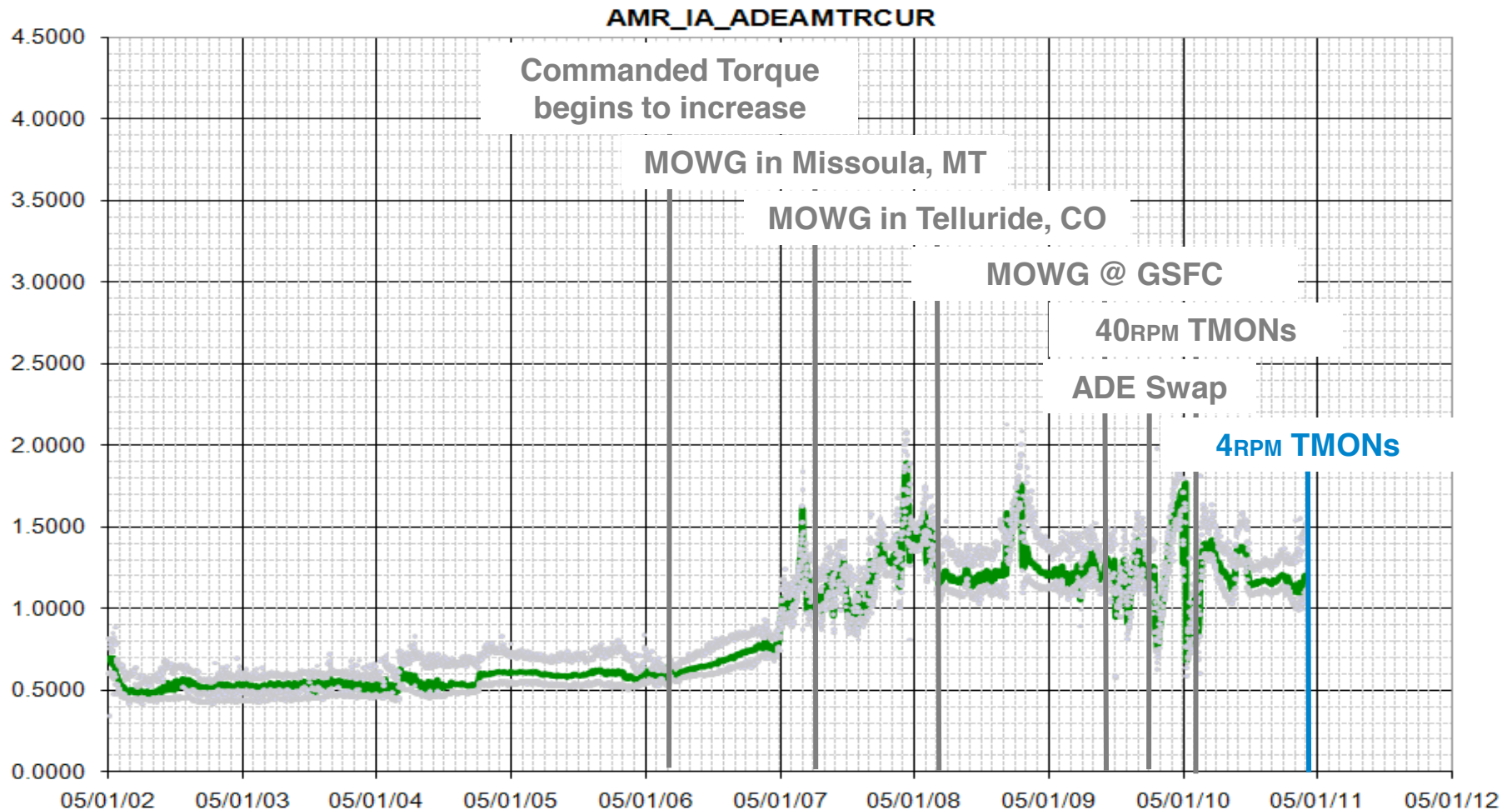
(Summary 2010 – 2011)



- **02/02/10: Antenna Drive Electronics A (ADE-A) anomaly and swap to ADE-B**
- **May 2010: Meeting with AMSR-E Team at GSFC**
 - NASA/JAXA discuss Telemetry Monitors (TMONs) to monitor ADA performance at 4 RPM
- **June 2010: NASA uplinks & enables 40 RPM TMONs (Except Command Torque)**
 - JAXA modifies AMSR-E internal fault management persistency from 1 → 80 sec to allow time for 40 RPM TMONs to command controlled spin-down in the event of an ADA anomaly
- **September 2010: JAXA recommends additional TMONs for use at 4 RPM due to instrument fault management not being designed to function when AMSR-E is rotating at 4 RPM (Additional information received from JAXA in October 2010)**
 - NASA develops five (5) 4 RPM TMONs & common response SCS #104 (spin-down to 0 RPM)
 - NASA also develops TMON #73 and SCS #32 to autonomously enable the 4 RPM TMONs after fault detection by the 40 RPM TMONs
- **April 2011: NASA uplinks and enables 4 RPM TMONs**
- **June 2011: Meeting with AMSR-E Team in Ashville, NC**
- **July 2011: NASA uplinks and enables 4 RPM Master TMON (TMON #73)**
- **September 2011: NASA enables commanding for Commanded Torque TMON (#40)**
- **October 2011: Antenna Drive Assembly (ADA) commanded torque anomaly and spin down to 0 RPM on 10/04/2011**



Commanded Torque Life of Mission



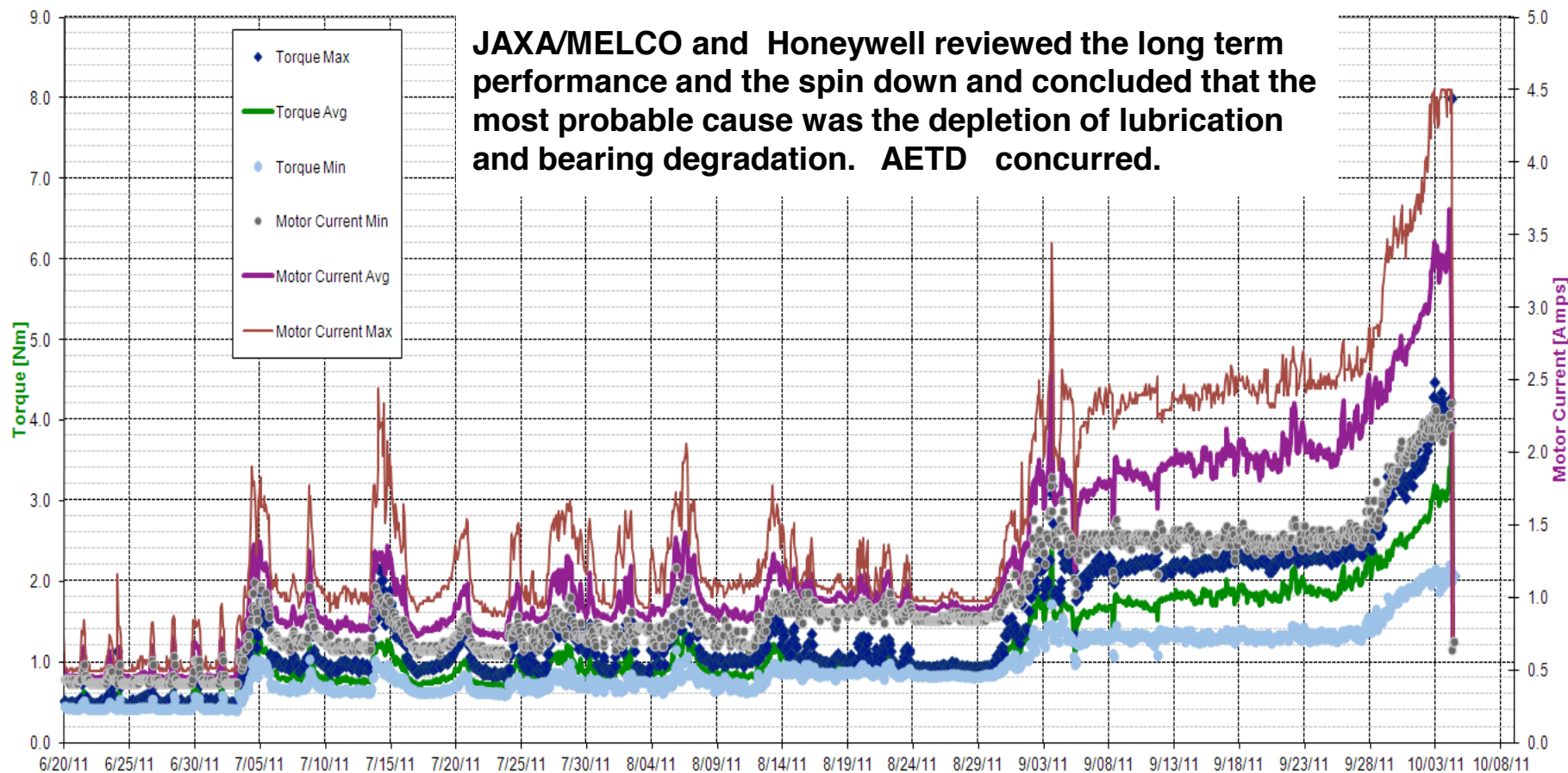


Command Torque & Motor Current

(6/20/2011-10/4/2011)



Commanded Torque & Motor Current





AMSR-E ADA Anomaly

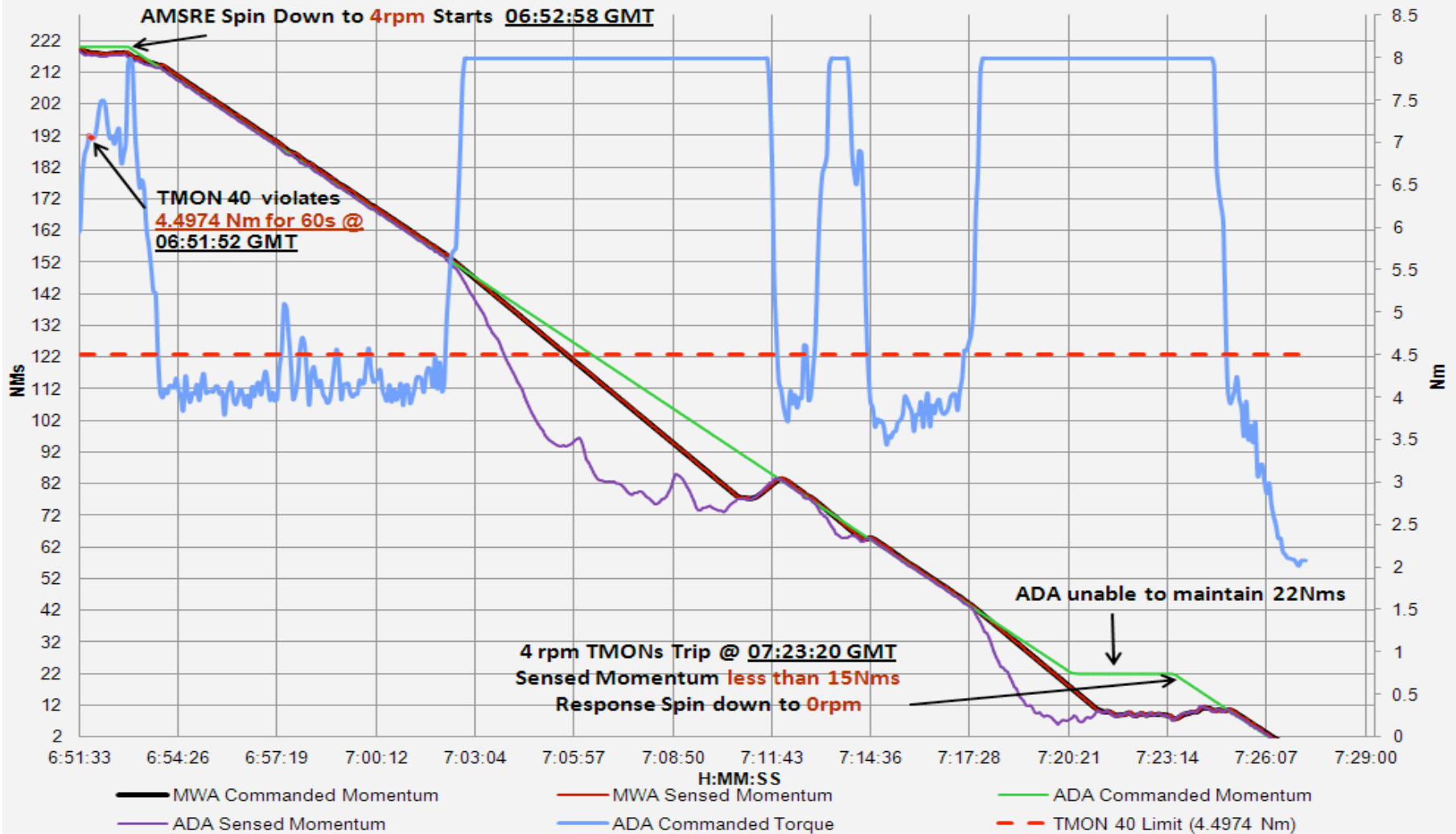
(October 4, 2011)



- **After several months of relatively quiet behavior, the AMSR-E Antenna Drive Assembly (ADA) motor current and commanded torque began to rapidly increase in late-September/Early October 2011**
 - AMSR-E began exhibiting anomalous behavior on October 4, 2011
- **Spacecraft Fault Management (FM) detected the anomaly, and responded by commanding a controlled spin-down to 4 RPM**
 - This response successfully mitigated ~220 NMS of residual momentum by commanding a controlled spin-down prior to AMSR-E's coast-run-down sequence executing
- **Approximately 32-minutes after commanding the controlled spin-down, the AMSR-E 4 RPM Telemetry Monitors (TMONs) detected that AMSR-E was not able to maintain 4 RPM and commanded a controlled spin-down to 0 RPM**
- **The AMSR-E Instrument Operations Team (IOT) had previously consulted the instrument manufacturer (MELCO) and reported this to be normal behavior for an instrument well beyond its design life (3-years) and possibly approaching end-of-life conditions.**
 - **GSFC AETD mechanism experts concur with the JAXA/MELCO assessment. Possible Causes:**
 - » Increase of the lubrication viscosity (deterioration of the grease, abrasion of the bearing & sludge of the abrasion powder)
 - » Similar behavior of the QuikSCAT drive motor



Timeline and ADA/MWA performance during AMSR-E Spin Down (October 2011)

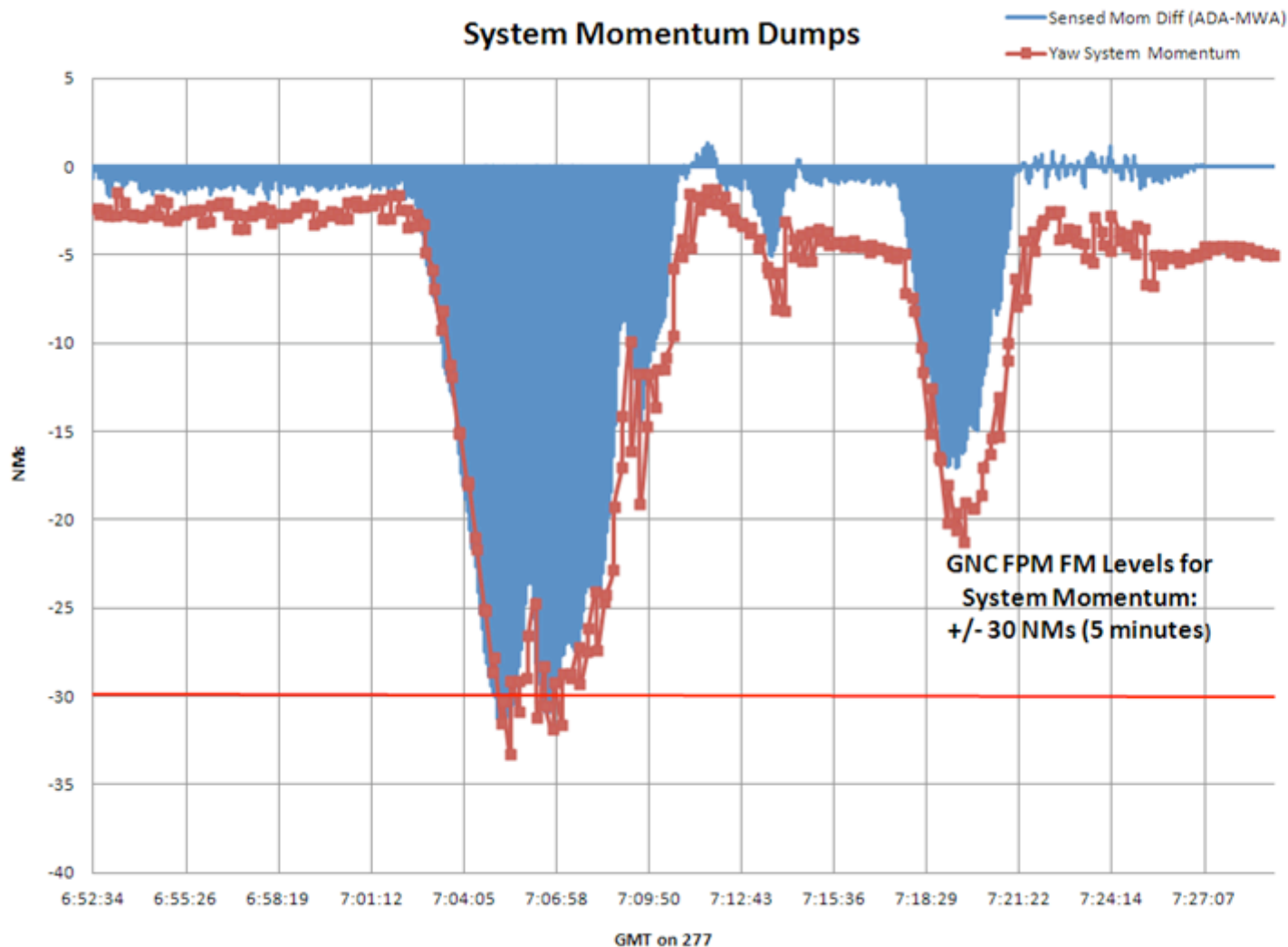




System Momentum during spin down



System Momentum Dumps



This slide shows how close the S/C came to going into Safe state due to a system momentum trip. FM trips with a 30 Nms in any axis for 5 minutes. Nominally in Science the S/C is well controlled within 8 Nms, almost never getting as much as 10.

During the AMSR spin down the error reached in 33 Nms, for roughly 2 minutes just short of tripping FM.

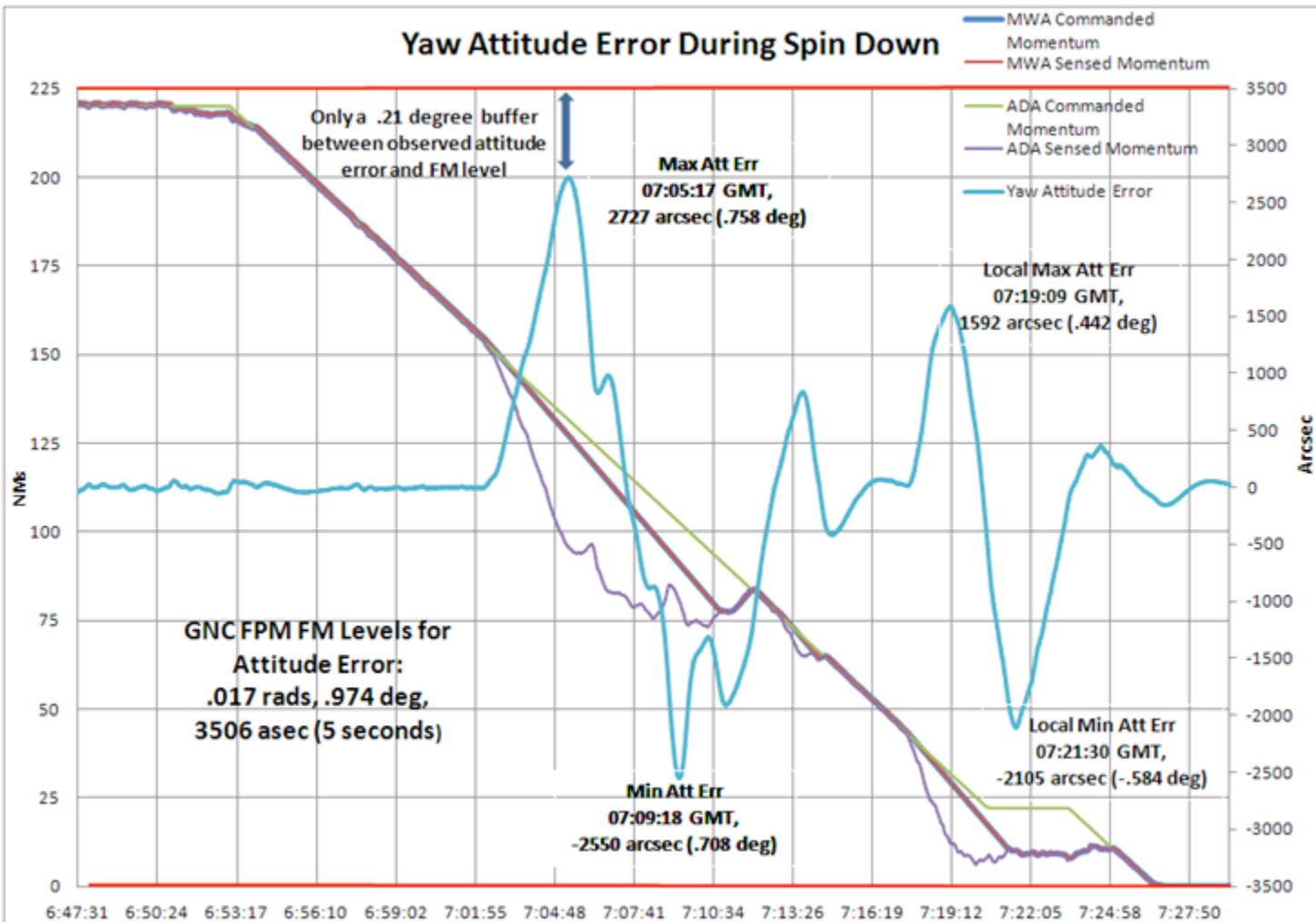
The red line shows the system momentum levels, while the blue shows the difference between the MWA and ADA. This illustrates that the AMSR imbalance contributed to all the system momentum on the S/C.



Yaw Attitude Error during spin down



Yaw Attitude Error During Spin Down



This slide shows how close the S/C came to going into Safe state due to an attitude error trip. FM trips with a .97 degree attitude error in any axis for 5 seconds. Nominally in Science the S/C is well controlled within .007 degrees, almost never getting an error of .01.

During the AMSR spin down the error reached in .758 degrees, just .21 degrees short of tripping FM.

Note that the momentum dump at 07:21 caused the S/C to have a larger error on the second swing negative as the momentum was taken out.



Anomaly Recovery Process

(Spacecraft safety is ESMO's #1 priority)



- **Take pre-approved actions to pre-defined problems**
- **If the pre-approved action does not work, or if the problem is a new one without a pre-defined response, then ESMO will assemble the appropriate experts and lead the NASA Anomaly Recovery Team (ART)**
- **AMSR-E Spin Down Anomaly Recovery Team (ART) members:**
 - JAXA AMSR-E Instrument Operations Team (IOT)
 - Aqua Flight Operations Team (FOT)
 - Aqua/Aura Flight Software (FSW) Maintenance (AFM) Team
 - Northrop Grumman Aerospace Systems (NGAS) – the s/c manufacturer
 - ESMO Management Team
 - EOS Science Interface Manager
 - Mechanical Systems and GN&C experts from AETD
 - GSFC Mission Assurance
 - Aqua Mission Director
 - Communicated with the Aqua Project Scientist & Aqua Science Team



Anomaly Recovery Process



- **The ART established the AMSR-E Spin-up Working Group (SUWG) and immediately began a course of action to investigate the anomaly and develop a recovery plan. This course of action included:**
 - **Reviewing previous Aqua safe events**
 - **Reviewing the spacecraft performance during the spin down**
 - **Determining potential effects of spinning up AMSR-E on the spacecraft**
 - **Identifying risks and developing potential mitigation plans**
 - **Conducting Spin Up Recovery meetings and teleconferences with**
 - » **JAXA – Reviewed JAXA/MELCO Anomaly Report & generated questions**
 - » **NGAS – Requested to perform dynamic model simulations and make recommendations for any fault management threshold changes**
 - » **IOTs – Requested to review Safe and Survival instrument configurations and make recommendation for changes if necessary/desired**
 - **Developed list of concerns and worked with the spacecraft manufacturer to develop list of risks and mitigation strategies.**
- **ART Meetings and Teleconferences were attended by Aqua Project Scientist, EOS Project Scientist, MODIS Project Scientist, CESES & AIRS instrument team leads and AETD as appropriate**



Anomaly Recovery Activities



- **Held a face-to-face technical meeting with JAXA, the Spacecraft Manufacturer (NGAS) and GSFC Flight Software (FSW) Teams**
- **Identified and developed modifications to procedures, telemetry monitors (TMONs), stored command sequences (SCSs)**
- **The FOT with NGAS and the Aqua/Aura FSW Maintenance (AFM) Team reviewed and tested all FSW changes**
- **Identified training for planned simulations and rehearsals**
- **Tested and simulated planned and contingency procedures**
- **Held Independent technical Readiness Review**
- **Completed Safe-Mode recovery simulations**
- **Completed NASA HQ Review of proposed recovery activities**
- **Conducted Operational Rehearsal with full-up team**
- **Performed Command Authorization Meetings (CAMs) as required**
- **Completed all pre-recovery/test command activities**
- **Executed the recovery/test activities**
- **Conducted post-recovery/test reviews and captured lessons learned**



Anomaly Recovery Timeline



- **01/26/2012: JAXA requests 3 stage recovery process**
- **02/06/2012: Stage 1 – Instrument turn-on without rotation**
- **07/18-20/2012: Technical Meeting with JAXA at GSFC (3-days)**
- **08/21-24/2012: NGAS at GSFC for FOT simulations (4-days)**
- **09/06/2012: Stage 2 Independent Technical Review at GSFC**
- **09/12/2012: Stage 2 Briefing/Review with NASA HQ**
- **09/14/2012: FOT Run-for-Record simulations of Stage 2 activities**
- **09/17/2012: Operational Readiness Rehearsal (ORR) of Stage 2 activities**
- **09/19-21/2012: Stage 2 – Spin-up/Spin-down tests (3 per day – 2-days)**
- **09/26/2012: Telecon with Aqua IOTs and NGAS**
- **11/27/2012: Stage 3 Independent Technical Review at GSFC**
- **11/29/2012: Stage 3 Briefing/Review with NASA HQ & FOT Rehearsal**
- **12/03/2012: Operational Readiness Rehearsal (ORR) of Stage 3 activities**
- **12/04/2012: Stage 3 spin-up to 2.076 rpm**
- **12/07/2012: Post-activity spin-up performance briefing (all parties)**



AMSR-E Current Status

(September 2013)



- **On December 4, 2012, AMSR-E was successfully spin-up to 2.0767 rpm with JAXA, NGAS, FSSE, FOT and ESMO Management present. After initial orbit, AMSR-E achieved stable rotation and has continued to perform well ever since**
 - **01/08/2013: One-Month Performance Status Briefing**
 - **02/13/2013: Two-Month Performance Status Briefing**
 - **04/03/2013: Four-Month Performance Status Briefing (Charts-only)**
 - **06/03/2013: Six-Month Performance Status Briefing (Charts-only)**
 - **08/13/2013: ~Nine-Month Performance Status Briefing – no changes – no concerns**
- **Aqua Instrument Teams report all instruments continue to perform well with science unaffected by AMSR-E rotation at 2 rpm**
- **02/26/2013: Spacecraft Maneuver Concerns Action Closed**
- **03/11/2013: Met with JAXA Team in Tokyo, Japan**
 - **Spacecraft and Instrument performance continues to be very stable**
 - **JAXA continues to investigate how to process the cross-calibration data**
 - » Established manual process to perform geometric correction
 - » Working on manual process for radiometric correction
 - **May request slight adjustment to rotation rate**
 - **Will release 2-rpm data to users when radiometric calibration data becomes reasonable**
- **09/04/2013: Met with JAXA Team in Oxnard, California**



NASA Group Achievement Award

AMSR-E Recover Team



EOS Aqua AMSR Instrument Recovery Team
NASA Group Achievement Award
August 27, 2013

National Aeronautics and Space Administration

Presents the

Group Achievement Award

to

EOS Aqua - AMSR Instrument Recovery Team

*For efficient, effective, and exemplary engineering and safety analysis for
the safe recovery of the Advanced Microwave Scanning
Radiometer - EOS (AMSR-E) instrument.*



*Signed and Sealed at Washington, DC
this eighteenth day of July
Two Thousand Thirteen*

CF Boldt

Administrator, NASA



List of JAXA/MELCO AMSR-E Recovery Award Recipients



- **JAXA**

- Toshiaki Takeshima
- Susumu Saitoh

- **MELCO**

- Takaaki Ishikawa
- Toshihiro Obata



EOS Aqua AMSR Instrument Recovery Team
NASA Group Achievement Award
August 27, 2013



EOS Aqua AMSR Instrument Recovery Team
NASA Group Achievement Award
August 27, 2013